Pro & Cons of Current & Emerging Modalities

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Early Detection
- Visual detection
  - Advanced breast cancer

Standard Treatment
- Cauterization
- Exorcism
- Topical pain relieving ointment
- Special diets

The Renaissance - 1500s
- Radical mastectomy as treatment option
- Cauterization to control bleeding

Discovery of Radiation
- Roentgen discovery of x-rays in 1895
- Becquerel and Curie - work in isolating radium from uranium
- Radiation treatment as a cure
**X-ray Imaging - the Breast**

- Radiography – a sub-specialty in 1900’s
- X-ray imaging after World War II
- Analog tubes
  - Filters removed
  - Direct exposure films without a grid
- High radiation dose

**Benefit vs. Risks of Detection**

- Unpredictable examination
  - Low sensitivity
- High radiation dose
  - Damage to the breast skin

**Recommendation for Mammography**

- 1963 - HIP of New York began the first mammography trial
- 1971 - HIP reports the mammography reduces breast cancer deaths by 31% in women over 50
- Carcinogenic effects of mammography outweighed by benefits

**Dedicated Units**

- Better imaging techniques
  - Improved contrast
  - Increased resolution
  - Increased sensitivity
- Decrease radiation dose to breast
  - Reduced radiation risk

**Xeromammography**

- Tungsten target
- Dry process system
- Prints blue and white images
- Images viewed without a lightbox
- Larger latitude than screen-film
- High radiation dose

**Disadvantages of Mammography**

- Cancer is visualized as a white area within the background density of the breast
- Sensitivity will depend on breast density, patient age or hormone status
- Mammography tends to understate the multifocality of a lesion
- Inadequate compression and poor positioning will affect interpretation
Imaging Modalities
- Digital mammography – CM or DM
- Digital tomosynthesis including C view imaging
- CAD technology
- Ultrasound
- MRI
- Molecular imaging
  - PEM – FDG
  - Breast scintigraphy/
  - Lymphoscintigraphy/sentinel node mapping
- Computed tomographic laser mammography

Digital Mammography
There are two types of Digital Systems
- Digital Mammography
  - Cassetteless system
  - built-in detector technology
- Computer Mammography
  - Mammography Unit with IP plus Computer Reader (CR)
  - The IP is physically removed from the unit and inserted into the CR

Computed Mammography
- The image is captured on a IP using an analog mammography unit
  - IP (CR cassette)
  - Photostimulable phosphor (PSP)
- Processing reader
- Computer
- Display monitor

Computed Mammography Considerations
- Less expensive method of digital mammography
- A number of systems available
- Multi detectors
  - 18 x 24 cm
  - 24 x 30 cm

Imaging Plate (IP)
- Radiolucent front
- Layers
  - Protective
  - Phosphor
    - Photostimulable phosphor (PSP) – europium-doped barium fluorohalide
  - Conductive
  - Support
  - Light Shield
  - Backing

Image Capture
- X-ray photon strike phosphor crystals
- Electrons in crystal move to a higher orbital level (gain energy) in proportional to energy absorbed by the PSP
Computer Processing Reader

- Opens IP removes the PSP scans, reads, and erases the exposed PSP
  - Process takes about 60 sec.
- After scanning the PSP it returned to the IP and the IP is ejected from the CR reader

Within the CR

- An infrared light scans the phosphor in a raster pattern
- Provides energy to the trapped electrons in the phosphor center
- Laser causes the metastable electrons to return to the ground state.
- The electrons emit a blue/purple - visible light - as they relax to the lower energy levels.

Photostimulable Luminescence (PSL)

- The emission of bluish-purple light from electrons as they transition from higher energy to a lower energy state
  - A photomultiplier tube (PMT), photodetector (PD) or charge-coupled device (CCD) collects the blue/purple light given off by the trapped electrons as they return to their normal neutral state
  - ADC converts the light energy to a digital signal
    - Digital signal is sent to the computer for manipulation
  - DAC in LCD converts data back to a visible image

Erasure

- Some electrons will remain in the higher state
- IP left in the x-ray room will absorb radiation
- High intensity light will complete erase the PSP allowing reuse
- IPs must be erased every 48 hrs to remove background radiation even if not used
- The IPs must be erased before using if the last time of erasure is unknown

Advantages of CM

- No silver based film or chemicals
- Digital storage - reduced film storage costs
- Correction for over or under exposure - fewer retakes & lower overall dose to the patient
- Faster image acquisition
- Wide latitude allows imaging of a range of thicknesses on one exposure
- Images can be enhanced digitally to aid in interpretation.
- Images can be stored & transmitted electronically

Disadvantages of CM

- Handling & transport of IP- can introduce artifacts eg scratches
- CM has inherent geometric unsharpness & resultant lower spatial resolution as compared to film/screen
- SNR issues due to sensitivity to scattered radiation
- IPs are expensive and can be damaged if dropped
- Repeated use results in image artifacts
Digital Imaging - FFDM

- Image is captured on a built-in digital detector (no cassettes)

FFDM Considerations

- Fixed detector size
  - Adjustment for small breast
  - Imaging the pectoral muscle on MLO
- Manufacture options
  - GE
  - Hologic
  - Siemens
  - GIOTTO
  - Planned Nuance
  - Sacra – Photon Counting

FFDM – Indirect Capture

- X-ray beam strikes the scintillator e.g. cesium iodide
  - Cesium iodide converts x-ray to light
- Light strikes a Photoconductive material e.g. amorphous silicon--i.e. photomultiplier or photodiode also called or thin film diodes (TFD)
  - TFD converts light to electrons
- Electron migrate to the thin film transistor (TFT)
  - TFT displays the digital signal

FFDM – Direct Capture

- X-ray beam strikes the photoconductor e.g. Amorphous selenium
  - Amorphous selenium converts x-ray to electrons
- Electron migrate to the thin film transistor (TFT)
  - TFT displays the digital signal

Thin Film Transistor (TFT)

- Made of electrodes, photoconductor and storage capacitor
- Collects electrons
- Generates an electric charge from each stored electron
- Allows charged pattern to be read pixel by pixel

Detector Elements (DELs)

- Located within the TFT
- DEL is the sensitive component of the TFT
- Collects electrons
  - DEL size controls the recorded detail, or spatial resolution, for the flat-panel device
  - DEL size contributes to the image blur present in a flat panel detector receptor.
    - The larger DELs in a flat panel detector cause more image blur.
- After the DELs are read, they are automatically erased--ready for another exposure.
Advantages of FFDM

- No plates to drop or damage
- No plates to be transferred
- Has increased DQE over CM
  - Very efficient in converting x-ray input signal into a useful output image

Disadvantage of FFDM

- Image lag or memory effect
  - The charge is trapped in the metastable band and is released slowly over time.
  - Image lag time varies and is shorter for flat-panel digital detectors based on indirect conversion

Photon Counting Capture

- Crystalline silicon detector
- Photon counting electronics
- Multi-slit collimator
  - Eliminates 97% of scatter without using grid
- Tungsten anode/Al filter

Advantage of Photon Capture

- Ergonomic design
- Warm detector
- Lower radiation dose
  - 40% less than FFDM
  - Robust
  - Temperature tolerant
    - 10-50 degrees C
    - 14-122 degrees F
  - No ADC – no lost signals
  - No ghost image – 100% fill factor

Important Consideration

- Positioning in digital is just as important as in analog imaging
- Digital can legally be performed only at facilities that are certified
- Technologist needs documented training

Contrast Enhanced Mammography

- Utilizes the association of cancer with increased vascularity
  - Cancers need oxygen and food
- Iodinated contrast agents injected into an arm vein
Need for Computer Aided Detection

• 5-10% of potentially detectable breast cancers can be overlooked by radiologists on a screening mammogram
• Double reading will reduce the failure to perceive an abnormality but double reading is expensive

CAD - Computer Aided Detection

• Combining digital technology with computers to pre-read the mammograms
• The computer will display suspicious areas, in effect acting as a second reader

How It Works

• The breast is mapped for a normal reference
• The image is analyzed
• Microcalcifications and abnormalities are enhanced
• Normal structures are de-emphasized

Uses of CAD

• CAD technology works with both digital analog mammography imaging systems, also with MRI and Ultrasound
• A analog mammography image can be fed into a digitizer which sends the signals to the CAD system

Sensitivity vs. Specificity

• High sensitivity will increase the false positive rate
• High specificity will reduce the number of false positives

Sound & Ultrasound

• Sound is a mechanical longitudinal wave
• Measured units - hertz (Hz)
• Ultrasound uses high frequency sound waves
Principle of Ultrasound

- Based on piezoelectric effect
- Crystals vibrate and produce sound waves
- Sound sent through tissues bounce back
- Returning echo causes crystals to vibrate in proportional strength
- Computer analyzes the strength of retuning echoes

The Transducer

- Converts electrical energy to acoustic pulses
- Receives the reflected echo and converts it to electrical signals
- Breast imaging uses
  - High frequency transducer (10MHz & above)
  - Linear array transducer

Ultrasound vs. X-ray

- Ultrasound uses:
  - No ionizing radiation
  - There are no documented risks or harmful bioeffects
- Sound cannot travel through a vacuum - a gel must be applied to the skin to act as a conductor

Use of Ultrasound

- Adjunctive imaging used in screening dense breast
- To determine if a mass seen on the mammogram is fluid-filled or solid
- To assess implants for leaks

Malignant Lesion

- Irregular shape/ ill-defined
- Angular /greater than 3 lobulations
- Microlobulated
- Spiculated margins
- Height greater than width
- Hypoechoogenicity
- Attenuating distal echoes
- Duct extension

Benign Lesion

- Homogeneous hyperechogenicity
- Thin echogenic pseudocapsule
- Ellipsoid shape
- Fewer than 4 gentle lobulations
- Compressibility
Intermediate Lesion

- Echo texture
- Echogenicity similar to fat
- Normal or enhanced posterior echoes

Limitations of Ultrasound

- Only as good as the sonographer
- Sonographer must be able to differentiate between real and artificial echoes
- No nice landmarks
- Sound does not travel in a vacuum – gel needed
- Dedicated training needed to scan and interpret the images

Imaging Difficulties

- Cannot image microcalcifications
- Breathing and body size can affect imaging
- Normal folds or reverberations can suggest rupture on implant imaging
- The lactating breast can suggest pseudolesions

Doppler Effect

- The use of high frequency sound to image moving structure such as blood flowing in a vessel
- Assigning different colors to blood flow
- Depends on velocity and direction – (To vs. Away from the transducer)

3-D Color Doppler

- An technology used to display blood flow in the breast
- Could be used to image highly vascular cancerous lesions

Volumetric Imaging

- SomoVu system
- Use of a single probe sweep using volume imaging protocol
Elastography

- Uses information from the ultrasound signal used to produce an image displaying the elastic properties of breast tissue
  - Differences in tissue stiffness
  - Cancers hard vs. Normal breast tissue

Magnetic Resonance Imaging (MRI)

- No x-ray
- Complex magnetic properties
- Imaging performed with a paramagnetic compound – major element includes gadolinium

MR imaging of the breast approved by the FDA since 1991

What Is MRI?

- The interaction of body tissue with radio waves in a magnetic field
- Echoes or signals from the body are continuously measured by the MRI scanner
- A digital computer reconstructs the echoes into images of the breast

Why Contrast?

- Malignant lesions enhance and wash out rapidly
- Benign lesions enhance and wash out slowly

The Procedure

- The patient lies prone on the table with the breast falling into specialize breast coils
- The table slides into the bore
- Numerous points are sampled
- The examination can last 30-40 mins

Uses of Breast MRI

- Map tumor extent - as a staging tool to evaluate treatment options
- Locate retroareolar cancer
- Detect multifocal/multicentric diseases
- Detect recurrence
- Evaluate dense breast
Uses of Breast MRI
- To evaluate positive surgical margins for residual cancer
- To evaluate the effects of chemotherapy response
- To distinguish post-operative or post-radiation scarring from cancer
- To evaluate implants

Risks and Complications
- Metallic dangers
- Poorly visualizes the axillary nodes
- Cannot image calcifications
- Expensive
- Time consuming
- Uses contrast – danger of NSF (nephrogenic systemic fibrosis)

Contraindications to MRI
- Cardiac pacemakers
- Aneurysms clips (intracranial)
- Intraocular ferrous foreign bodies
- Pregnant patients should consult their physician before imaging

Limits of Breast MRI
- High sensitivity but low specificity
- MRI will enhance fibroadenomas, and areas of inflammation

Magnetic Resonance Spectroscopy (MRS)
- Noninvasive imaging
- Measures the functional breast cancer byproduct – choline
- Uses high-field MR scanners
- Prevents unnecessary breast biopsies

Molecular Imaging
- Mammography findings are characterized by the difference in appearance between normal and suspicious breast tissue
- In molecular imaging the findings are based on how cancerous cells function
  - Positron Emission Mammography (PEM)
  - BSGI - breast scintigraphy or scintimammography
  - Lymphoscintigraphy – sentinel node mapping
**Positron Emission Mammography (PEM)**
- Uses fluorodeoxyglucose (FDG), a radioactive tracer that is injected into the arm vein
- Special gamma scanners detect the radiation emitted

**PEM Technology**
- Cancerous tissue uses vast amounts of sugar
- Radioactive substance is metabolized in the body like sugar
- The tracer will go to the tissues that are most active

**Use of FDG-PEM**
- For patients with ambiguous mammogram
- To stage lymph node involvement
- Detect current and/or recurrent metastases
- Discriminating fibrotic scar, necrosis or tumor
- Staging and restaging
- Imaging augmented breast

**Advances in PEM Imaging**
- Combination or fusion technologies – combining PEM and CT or MRI
  - Enables functional information of PEM to be fused with high-resolution anatomic images of CT or MRI
  - MRI offers high sensitivity with no radiation risks

**Precautions of FDG-PEM**
- Patient must fast before the scan
- Patient must lie still for 60-90 minutes after the FDG injection
- No vigorous exercise allowed 48 hours prior to a PEM scan

**Limits of FDG-PEM**
- Tumor size and cell type affects PEM accuracy – cannot detect cancers smaller than 1cm
- PEM cannot replace sentinel node mapping
- Inflammation/infection/surgery distort PEM results
Breast-Specific Gamma Imaging (BSGI)

- Injection of the drug technetium-99m(Tc99m) sestamibi
- Tracer accumulates in malignant lesions
- Mild compression of breast

Uses of Scintimammography

- Patients with indeterminate mammogram not referred for biopsy
- Patients with dense breast
- Breast cancer staging to detect
  - multifocal disease
  - axillary node involvement
  - extent of primary lesion
  - secondary lesions

Disadvantage of Scintimammography

- Does not detect lesions smaller than 1cm
- Some benign diseases give a false positive results
- Skin folds or muscles can mimic axillary uptake
- The radiopharmaceutical must be properly injected
- Uses 8-10 times the radiation of mammogram

Lymphoscintigraphy

Sentinel node mapping

- The injection of a radiopharmaceutical into the subareolar lymphatic plexus (or lesion)
- The tracer travels to the sentinel node - identifying that node for dissection and eliminating the need for extensive lymph node dissection

Limitation of Lymphoscintigraphy

- Poor visualization of deep lymphatic system

Computerized Tomographic Laser Mammography - CTLM

- The breast is scanned 360-degrees
- The hemoglobin in a vascular tumor absorbs the CTLM laser light
- Temperature differences indicates tumors
- Each breast scan takes 15-minutes
  - CTLM approved in Canada, Europe and Asia

Source: http//www.imds.com
CTLM Procedure
• Patient lies on a table with breast suspended through a hole
• Low-wavelength laser scans the breast
• Bright green 3-D cross-section image of the breast obtained
Source: http://www.imds.com

Advantages and Disadvantages
Advantages
• No compression or radiation
• Can image dense breast
• Can differentiate cystic vs. Solid lesion
• Can image implants
Disadvantages
• Cannot detect microcalcifications
• Difficult to image small breast

Optical Imaging
• Use of infrared light to penetrate breast tissue
• Extra blood vessels clustering a tumor distort light in a characteristic way
• Process will highlight the presence of tumors

Cone Beam Breast Computed Tomography - CBBCT
• The patient lies on a cushioned table with a cutout in the middle
• Breasts are suspended through an opening
• The scanner takes 360-degree scans without compression – 300 images in 10 sec
• Can distinguish small lesions and can image calcifications
• Drawback: – Difficulty imaging details of calcifications

Digital Tomosynthesis
• 15 exposures in 4 sec
  – Tube sweeps from -7 to 0 to +7
• No movement of the patient
• Options: 2D, 3D, COMBO or C view
  – Tomo does not use grid

Why Breast Tomosynthesis (3D mammography)?
• Tissue superimposition hides pathologies in 2D
• Tissue superimposition mimics pathologies in 2D
3D Improves Visibility by Reducing Tissue Superimposition

How Does Tomosynthesis Work?

3D Principle of Operation
- X-ray tube moves in an arc across the breast
- A series of low dose images are acquired from different angles
- Total dose approximately the same as one 2D mammogram
- Projection images are reconstructed into 1 mm slices

Slabbing
- Slice #1 is closest to the detector
- Highest slice # is closest to compression paddle
- Reconstruction is always in 1 mm thick slices
- A breast 4 cm thick = 40 slices
- A breast 5 cm thick = 50 slices
- Slices can be slabbed together to visualize calcifications

DBT — Visualization
A DBT reconstruction
- 30-80 slices parallel to the detector plane
- 1 mm slice thickness
- 100 µm in-plane pixel size
Visualization software functions
- Paging through DBT slices
- Window level
- Zoom in / zoom out
- Field of view magnifier

Advantages
- High resolution cross-section 3-D images
- Eliminates overlapping structures
- The # of reconstruction images based on the breast thickness in mm.
Biopsy proven cancer

Mammographically occult biopsy proven cancer

Mammographically occult biopsy proven cancer

Benign. Superimposed parenchyma

Benign. Superimposed parenchyma

Lesion not seen on mammogram
Motion Unsharpness

- Most common patient-related artifact*
- Motion: local/regional or involves the entire breast
- Gross or Subtle
- Repeats for motion increase radiation dose
- Potential to miss breast cancer

*Geiser et al: Challenges in Mammography; AJR:197, December 2011

Factors contributing to Motion Unsharpness

- Inadequate Compression
- Poor Positioning
- Exposure Time
- Patient Movement
- Heart Motion

2D vs 3D - Motion Unsharpness

2D Mammography
- Acquisition time is brief
- Captures a moment in time
- One image
- Technologists/radiologists adept at detecting motion
- Repeats are left up to the Technologist

3D Tomosynthesis
- Longer acquisition time
- Multiple image data set
- Images acquired over a period of time
- 3D motion occurs at about the same rate as 2D

3D Motion may be unrealized and unchecked

- Radiologists do not routinely review the projection dataset where motion can be confirmed or ruled-out
- Projection dataset may not be available to the radiologist (BTO)

*I t is up to the technologist to detect motion and repeat when advised
Tomosynthesis and Motion

**Important notes:**
- Motion can occur at one point, multiple points or through-out the duration of the entire projection series
- Motion can occur at different areas of the breast, which may or may not impact breast tissue
- May affect conspicuity, sharpness of detail

Appreciating 3D Motion: QC Review

- Motion can be visible on both projection & tomosynthesis datasets
- Tomosynthesis Reconstruction
  - More difficult to detect/confirm motion on reconstruction
  - Unsharpness in the tomosynthesis dataset
  - Non-linear movement of calcifications
  - Objects or lesions look sharp in one view, but not the opposing view
- Projection Series
  - Most efficient way to detect motion
  - Review series at Selenia® Dimensions® System

Appreciating 3D Motion

**Projection Series**
- The x-ray tube moves in a path parallel to the chest wall
- The resulting breast image(s) and objects should move smoothly along this same pathway
  - Medial to Lateral /Lateral to Medial
- Anterior/posterior movement of the breast images or objects indicates motion

If objects in the breast seem to wiggle and bounce anterior to posterior, consider motion
Arc of motion of x-ray tube, showing individual exposures

Reviewing Projection Images for Motion
- Review the 15 Projections
  - Cine Mode
  - Moderate to fast speed

Appreciating 3D Motion: Notes
- Chest wall
  - Movement of the Pectoral Muscle
  - Structures that shift in and out of view
- Inframammary fold
  - Abdomen motion
  - Determine if it impacts the inferior and posterior breast
- Calcification
  - Should move in a straight line parallel to the chest wall
  - More evident with large chunky calcifications
- Axilla
  - Lymph Nodes shift back and forth or out of view

Movement of Veins
Movement of Veins

Movement of Calcifications

Minimize Motion: Breathing Technique

- Can be a challenge with the size of the detector
- The arch/slices of the tomosynthesis due to patient thickness
Engage Patient in Technique

• Inform the patient of the new 3D/2D technology
• Describe the c-arm movement
• As typical for standard mammography, explain that motion can affect the image
• Instruct the patient in the breathing technique
  – Explain that STOP BREATHING means just that
  – Patient SHOULD NOT take in a breath & hold it

Breathing Technique: the Steps

• Compress exposure controls
• While the x-ray tube is moving into position to start the tomosynthesis:
  – Instruct patient to STOP breathing for the 3D acquisition
• At the conclusion of the tomosynthesis sweep
  – Instruct patient to breathe
• As the tube moves to center, listen for the completion of the grid movement
  – Then instruct the patient to stop breathing for the 2D acquisition

Motion Repeats

• The significance of motion unsharpness on Tomosynthesis is not yet known
• How and when to repeat an image should be directed by the supervising radiologist

Tomosynthesis with Generated 2D Images – The C-View

The Option of the C-View

• The C-view offers a reconstructed 2-D image of the breast without the additional radiation
• Conventional digital = 2-D
• COMBO = 2-D + 3-D
• Alternative reduced option
  – 3-D + C view

Generating 2D Images

• Perform a standard tomosynthesis scan
Generating 2D Images

- Perform a standard tomosynthesis scan
- Reconstruct tomosynthesis slices

15 Projection Images

55 Tomosynthesis Slices*

Reconstruction Algorithm

*Average slices based on 5 cm compressed breast

Generating 2D Images

- Perform a standard tomosynthesis scan
- Reconstruct tomosynthesis slices
- Synthesize 2D image
- Available in any tomosynthesis view

Software Algorithm

*Average slices based on 5 cm compressed breast

Image Comparison: Case 1

2D Tomosynthesis Slice Generated 2D (C-view)

U.S. Dose Comparison

Combo Mode
- Tomo + FFDM
- 12 second scan time
- ACR Dose = 2.65 mGy

TomoHD Mode
- Tomo + Generated 2D
- 4 second scan time
- ACR Dose = 1.45 mGy

- Scan Time Reduction
- Lowers Risk of Patient Motion
- Patient Dose Reduction

Radiation Dose

- 1.2 mGy – 2D
- 1.45 mGy – 3D
- 2.65 mGy – COMBO
- Imaging implants in 3D = more radiation to patient because lower kVp used
- ACR recommends
- 3 mGy (0.3 rad or 300 mrad) with a grid
- 1 mGy (0.1 rad or 100 mrad) without a grid

Potential Uses of DBT

- Detection / Screening - especially women with dense breasts
- Diagnostic work-up/ Characterization / Problem solving
- Reduce recall rate
Drawbacks of DBT

- Motion artifacts hard to detect at radiologist workstation
  - Projection vs reconstruction images
  - Radiologist views reconstruction images
- Large number of images
- Degraded imaging of calcifications
  - Slabbing will help
- Tomo not possible for FB, Mag and if the breast is more than 24.5 cm
- Total exposure time for COMBO ≈ 12 sec

Conclusion

- Mammography is still the most comprehensive tool in the fight against breast cancer
- Adjunctive modalities are available and should be utilized

References & Image Source

- http://www.rpi.edu/~newelj/eit.html
- Hologic.com
  - Images and data courtesy of:
    - Netherlands Cancer Institute – Antoni Van Leeuwenhoek Hospital, Amsterdam Holland
    - Massachusetts General Hospital, Boston MA USA
    - Centre de Radiologie et d‘Echographie du Docteur Joussier, Paris France
    - Dartmouth Hitchcock Medical Center, Lebanon NH USA
    - Magee Women’s Hospital, Pittsburgh PA USA
    - University of Iowa Health Care, Iowa City IA USA
    - Yale University School of Medicine, New Haven CT USA

Thank You!!